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Force-velocity characteristics and maximal anaerobic power in male recreational marathon runners

Running head: Maximal anaerobic power in marathon running

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Abstract

The aim of the present study was to examine the relationship of force-velocity (F-v) characteristics with age and race time in marathon runners. One hundred thirty five male marathon runners (age 44.2±8.8 years, height 176±6 cm, body mass 24.7±2.6 kg.m^{-2} and personal record 4:02±0:45 h:min), separated into eight age groups (<30, 30-35, ..., 55-60, >60 years), performed a F-v test on a cycle ergometer consisted of four 7s sprints. The older age groups had the lowest scores in maximal pedalling velocity (v_0; $p<0.001$, $\eta_p^2=0.244$), relative (rPmax; $p=0.001$, $\eta_p^2=0.176$) and absolute maximal power (Pmax; $p=0.009$, $\eta_p^2=0.135$), whereas no difference in maximal force (F_0; $p=0.558$, $\eta_p^2=0.044$) was shown. Race time correlated moderately with F_0 ($r=0.31$, $p<0.001$) and Pmax ($r=0.30$, $p=0.001$). The small magnitude of age-related differences in anaerobic power among most age groups indicated that humans without muscle strength/power training might maintain anaerobic power indices till their 60's.

Keywords: aging, anthropometry, cycle ergometer, muscle strength, speed

Introduction

Exercise training has been routinely used in research modelling healthy ageing, especially considering the beneficial role of aerobic exercise for cardiovascular health (Hoffman & Krouse, 2018; Montero & Diaz-Canestro, 2016). Accordingly, several studies examined age-related differences in endurance athletes and showed that regular endurance training attenuates the decline in endurance with ageing (Knechtle & Nikolaidis, 2018; Lepers & Stapley, 2016; Tanaka & Seals, 2008). On the contrary, little information exists with regards to the decline of parameters not related to endurance performance with ageing (e.g. anaerobic power, in endurance athletes). Marathon running is an endurance sport of increasing popularity (Cuk, Nikolaidis, & Knechtle, 2019; Lepers & Cattagni, 2012) and the study of marathon runners across lifespan could enhance our knowledge about whether engagement in this sport might also attenuate the decrease of anaerobic power. Marathon runners are characterized by a relatively low anaerobic power compared to athletes running shorter distances (Legaz-Arrese, Munguía-Izquierdo, Carranza-García, & Torres-Dávila, 2011; Vuorimaa, 1996). For instance, in a 20s maximal anaerobic running test, marathon runners scored lower than sprinters and middle distance runners (Vuorimaa, 1996). Furthermore, in a comparison of distances from 100m to marathon, marathon runners had the lowest scores in the Wingate anaerobic test (WAnT) (Legaz-Arrese et al., 2011).

The ability of the human body to generate maximal power (Pmax) is linked to a host of performance outcomes and sporting success (Cross, Brughelli, Samozino, & Morin, 2017). Maximal anaerobic power (Pmax) and force-velocity (F-v) relationships characterize limits of the neuromuscular system to produce power and their measurement has been a common topic in research for the last years (Cross et al., 2017). The F-v relationship, well established for an isolated muscle (Fenn & Marsh, 1935), has been also documented for multi-articular movements such as cycling, where an increased braking force was associated with decreased pedalling velocity (Vandewalle, Pérès, Heller, & Monod, 1985). The F-v test (Driss & Vandewalle, 2013; Vandewalle et al., 1985) has been widely used in athletes such as judoists, boxers, taekwondo athletes (Busko, 2016), team handball (P.T. Nikolaidis et al., 2016), soccer (Nikolaïdis, 2012), tennis (Durand, Ripamonti, Beaune, & Rahmani, 2010) and cyclists (P.T. Nikolaidis & Papadopoulos, 2011), and non-athletes, such as elder women aged 50-70 years (Oesen, Bachl, & Baron, 2015) and 66-82 years (Kostka et al., 1997). However, to the best of our knowledge, the F-v test has not been used previously in male marathon runners.

With regards to age-related changes in Pmax, it has been shown that this parameter assessed by a bipodal vertical jump test was reduced at the age of 75 years, both in absolute and relative units, to about 50% of the value measured at the age of 20 years (Grassi, Cerretelli, Narici, & Marconi, 1991). Moreover, Grassi et al. (1991) suggested that changes after the age of 45 years should be attributed to a decrease in muscle mass. Pmax might be associated to performance in marathon running as it has been observed to be related to the cost of running in ultra-marathon runners (Giovanelli, Taboga, Rejc, & Lazzer, 2017). Moreover, a decrease of Pmax after a marathon run has been shown previously (Petersen, Hansen, Aagaard, & Madsen, 2007).

The knowledge about Pmax and its components (i.e. F and v) would be of both theoretical and practical importance for gerontologists and physiologists interested in the mechanisms of ageing, and for coaches and fitness trainers working with marathon runners, respectively. The aim of the study was to assess the F-v profile of recreational marathon runners and examine the relationship of F-v characteristics with age, performance and anthropometry. Even if F-v characteristics were not related with marathon race time, they would aid endurance runners performing tasks with vigor in their daily life (Cattuzzo et al., 2016) or coping with increased muscular demands during a race (e.g. ascents or descents; Padulo et al., 2013). Considering previous research on the effect of aging on Pmax, assessed by vertical jump (Grassi et al., 1991), it was hypothesized that older marathon runners would exhibit lower Pmax than their younger counterparts. Furthermore, since a recent study did not find any relationship between F-v characteristics and race time in female marathon runners (P. T. Nikolaidis, Rosemann, & Knechtle, 2018), it was hypothesized that a similar trend would be observed in male marathon runners, too, where F-v characteristics would be expected to be relatively low compared to other physically active groups (e.g. master cyclists) (Chamari et al., 1995).

Methods

Study design

To investigate the F-v characteristics in recreational marathon runners a cross-sectional study design was applied, in which marathon runners were invited to participate in a single-day experimental session. The study had been advertised through popular websites for endurance runners in the spring of 2017. Inclusion criteria were the documented finish in the Athens marathon 2016 - which was double-checked in the results provided by the official website of the race (https://www.athensauthenticmarathon.gr/site/index.php/en/) - and the intention to participate in the Athens marathon 2017. Exclusion criterion was the existence of any illness or injury inhibiting in participation to exercise testing. During September and October 2017, the participants visited the laboratory where they performed a F-v test on a cycle ergometer. Prior to exercise testing session, participants received detailed information about all procedures and became familiarized with the laboratory setting. All subjects provided written informed consent and the study was conducted in accordance with the Declaration of Helsinki. The protocol was approved by the local institutional review board.

Participants

One hundred thirty-five recreational marathon runners (age 44.2±8.8 years, height 176±6 cm, body mass 24.7±2.6 kg.m^{-2} and personal record 4:02±0:45 h:min, completed marathons in the past: median 3, interquartile range 2-6) mostly from the area of Athens volunteered to participate in this study. During the last month prior to testing, they were performing 4.3±1.3 running sessions weekly corresponding to weekly running distance 52.7±21.1 km. Participants were classified in eight 5-year-intervals age groups (<30 years, n=7; 30-35 years, n=9; 35-40 years, n=25; 40-45 years, n=34; 45-50 years, n=31; 50-55 years, n=16; 55-60 years, n=6; and >60 years, n=7). In addition, they were grouped into quartiles based on their most recent race time: Q1 (2:27 - 3:29h:min, n=32), Q2 (3:30 - 3:59h:min, n=33), Q3 (4:00 - 4:27h:min; n=35) and Q4 (4:28 - 6:30h:min, n=33).

Procedures

Anthropometry. The height and body mass of participants were assessed in underwear clothing and barefoot using a portable stadiometer (SECA, Leicester, UK) to the nearest 0.001 m and an electronic weighing scale (HD-351; Tanita, Arlington Heights, IL, USA) to the nearest 0.1 kg, accordingly. Skinfolds' thickness was measured by a calliper (Harpenden, West Sussex, UK) the nearest 0.2 mm. Mid-thigh circumference was measured using an ergonomic circumference tape (SECA 201, Leicester, UK). Body fat percentage (BF) was estimated from skinfolds using the equation BF=-41.32 + 12.59×logx, where x was the sum of ten skinfolds (cheek, wattle, triceps, subscapular, chest I, chest II, abdominal, suprailiac, front thigh and calf) (Parizkova, 1978). Fat-free mass (FFM) in kg was calculated as 'body mass - (body mass × BF / 100)'. Total thigh muscle cross-sectional area (CSA) was calculated as '(4.68 x mid-thigh circumference in cm) – (2.09 x anterior thigh skinfold in mm) – 80.99' (Housh et al., 1995). Body mass index (BMI) was calculated as the quotient of body mass (kg) to height squared (m^2).

Force-velocity test. A task-specific warm-up - consisting of 9-min cycling of moderate intensity and two sprints of short duration (2-3s) - was performed on a friction-loaded cycle ergometer (Ergomedic 828E, Monark, Sweden). The F-v test was employed to assess Pmax, expressed as W and as W/kg (rPmax), theoretical maximal pedalling velocity (v_0) in revolutions per minute (rpm) and force (F_0) in N. In addition v_0/F_0 was calculated in rpm/N. This test employed various braking forces that elicit different pedalling velocities in order to derive Pmax (Driss & Vandewalle, 2013). The participants performed four sprints, each one lasting seven seconds, against an incremental braking force (3, 4, 5 and 6 kg on a counterbalanced order) on a friction-loaded leg cycle ergometer (Ergomedics 874E, Monark, Sweden), interspersed by 5-min recovery periods. The seat height of the ergometer was adjusted to allow for a slight bend in the knee (approximately 175°) and in accordance with the participant's satisfaction (Trecroci, Formenti, Rossi, Esposito, & Alberti, 2017). Each sprint began with a flying start, i.e. as soon as pedalling velocity reached 50 rpm (revolutions per minute), the weight basket of the cycle ergometer was released manually and the braking force was applied. For each participant an individual linear regression was determined between peak pedalling velocity and braking force for each of the four sprints. F_0 and v_0 corresponded to the intercepts with F and v axes in the F-v graph. Pmax was calculated as $Pmax=0.25 \cdot F_0 \cdot v_0$ (Vandewalle et al., 1985). Vandewalle et al. (1987) highlighted the almost perfect inversely linear relationship between the braking force and pedalling velocity in male and female athletes of various sport disciplines. All laboratory measurements were performed by the same qualified (MSc and PhD in Exercise Physiology and Exercise Testing, experience of exercise test administration to >10,000 athletes in the last 14 years) investigator to ensure a high reliability of measurements.

Statistical analyses

Data were expressed as mean and standard deviation (SD). Normality was examined using Kolmogorov-Smirnov test and visual inspection of normal quantile-quantile (Q-Q) plots comparing probability distributions. One-way repeated measures analysis of variance (ANOVA) and a subsequent Bonferroni *post-hoc* test (if there were differences among groups) were used to examine the differences among age and performance groups, separately. Partial eta square (η_p^2) was used to interpret effect size (ES) of statistical differences for ANOVA and was classified as small ($0.010 < \eta_p^2 \leq 0.059$), medium ($0.059 < \eta_p^2 \leq 0.138$), and large ($\eta_p^2 > 0.138$) (Cohen, 1988). The relationship of F-v characteristics with age, performance and anthropometry was examined using Pearson's product moment correlation coefficient (r). The level of significance was set at $\alpha = 0.05$. Statistical analyses were performed using IBM SPSS v.20.0 (SPSS, Chicago, IL, USA) and figures were created using GraphPad Prism v. 7.0 (GraphPad Software, San Diego, USA).

Results

Profile of force-velocity characteristics

With regards to the outcome measures of the F-v test, v_0 was 195±16rpm (ranging from 149 to 243rpm), F_0 159±24N (102-231N), Pmax 790±126W (437-1166W), rPmax 10.3±1.5W/kg (6.2-14.7W/kg) and v_0/F_0 1.26±0.22 rpm/N (0.74-1.76 rpm/N). The F-v relationship of all participants was presented in **Figure 1**.

Differences in anthropometric and force-velocity characteristics among age groups

A moderate-to-large main effect of age group was observed on body mass (p=0.025, η_p^2=0.116), BMI (p=0.025, η_p^2=0.117), BF (p=0.034, η_p^2=0.110) and race record (p=0.025, η_p^2=0.119), but not on body height (p=0.261, η_p^2=0.066), FFM (p=0.098, η_p^2=0.089) and CSA (p=0.074, η_p^2=0.095) (**Table 1**). Athletes in age group 45-50 years were heavier and had a higher BMI than athletes in age group 35-40 years. A large main effect of age group on v_0 (p<0.001, η_p^2=0.244), rPmax (p=0.001, η_p^2=0.176), and a moderate main effect on Pmax (p=0.009, η_p^2=0.135) was observed with the older age groups showing the lowest scores, whereas no difference in F_0 (p=0.558, η_p^2=0.044) was shown (**Figure 2**). Particularly, >60 group had lower v_0 than <30 (-31 rpm), 30-35 (-25 rpm), 35-40 (-24 rpm) and 40-45 group (-23 rpm). Age group 55-60 had lower v_0 than <30 (-30 rpm), 35-40 (-23 rpm) and 40-45 group (-23 rpm), whereas age group 50-55 had lower v_0 than <30 (-22 rpm) and 40-45 group (-15 rpm). In addition, >60 group had lower Pmax than 35-40 (-168 W), 40-45 (-181 W) and 45-50 group (-176 W), and lower rPmax than <30 (-2.4 W/kg), 30-35 (-2.4 W/kg), 35-40 (-2.7 W/kg) and 40-45 group (-2.0 W/kg). Age was inversely correlated with v_0 (r=-0.46, p<0.001), Pmax (r=-0.26, p=0.002), rPmax (r=-0.37, p<0.001) and v_0/F_0 (r=-0.20, p=0.023), but not with F_0 (r=-0.04, p=0.683).

Differences in anthropometric and force-velocity characteristics among performance groups

Performance group differed moderately-to-largely for age (p=0.007, η_p^2=0.089), body mass (p<0.001, η_p^2=0.150), BMI (p<0.001, η_p^2=0.225) and BF (p<0.001, η_p^2=0.275), but not on body height (p=0.920, η_p^2=0.004), FFM (p=0.068, η_p^2=0.054) and CSA (p=0.060, η_p^2=0.055) (**Table 2**). The fastest performance group (Q1) was younger, lighter with a lower BMI and a lower BF than the slowest performance group (Q4).

Moreover, performance group differed moderately for on F_0 (p=0.013, η_p^2=0.080) and Pmax (p=0.035, η_p^2=0.065), with the slowest performance group (Q4) presenting higher scores than Q2 performance group, whereas no difference in v_0 (p=0.907, η_p^2=0.004) and rPmax (p=0.113, η_p^2=0.045) was shown (**Figure 3**). Race time correlated moderately with F_0 (r=0.31, p<0.001) and Pmax (r=0.30, p=0.001), but not with v_0 (r=-0.01, p=0.952) and rPmax (r=-0.01, p=0.935).

Relationship between force-velocity and anthropometric characteristics

V_0 correlated with FFM (r=0.24, p=0.006), F_0 with FFM (r=0.44, p<0.001) and CSA (r=0.34, p<0.001), and Pmax with FFM (r=0.54, p<0.001) and CSA (r=0.42, p<0.001).

Discussion

The main finding of the present study was that an inverse moderate correlation of the indices of muscle velocity (v_0) and relative power (rPmax) with age was observed, and the lowest scores was shown in the >60 age group. In addition, a moderate correlation of the indices of muscle force (F_0) and power (Pmax) with race time was found (i.e. the higher the F_0 and Pmax, the slower the race time) and the slowest group (Q4) presented higher scores than Q2. Furthermore, F_0 and Pmax correlated with non-fat mass of the body (FFM).

Profile of force-velocity characteristics

The F-v characteristics of participants (Pmax 790W, F_0 159N and v_0 195rpm) could be evaluated as relatively low compared with previous studies using the F-v test in physically active men or master cyclists (Chamari, Ahmaidi, Fabre, Massé-Biron, & Préfaut, 1995; Jaafar, 2017). For instance, physically active men's Pmax, F_0 and v_0 were 1115 W, 192 N, and 228 rpm, respectively (Jaafar, 2017). In addition, master cyclists had Pmax 1089 W (Chamari et al., 1995). The profile of participants was in agreement with existing research reporting relatively low scores of anaerobic power in marathon runners compared to shorter distances' runners (Legaz-Arrese et al., 2011; Vuorimaa, 1996). Consequently, the research hypothesis of a relatively low Pmax in marathon runners compared to athletes of other sports was confirmed, and this was accompanied by both relatively low v_0 and F_0.

Differences in anthropometric and force-velocity characteristics among age groups

The lower scores of rPmax and v_0 in the oldest age group were in agreement with the negative correlations of age with these two F-v parameters. These findings confirmed previous studies showing a decline of anaerobic power with ageing (Bonnefoy, Kostka, Arsac, Berthouze, & Lacour, 1998; Chamari et al., 1995). For instance, in a comparison between young (25 years) and master athletes (65 years) matched for body mass, body height and training, P_{max}, F_0 and v_0 were lower about 43%, 30% and 15%, respectively, in the older athletes (Chamari et al., 1995). A study of younger (23 years) and elder men (71 years) showed a decline of rP_{max} by 8% per decade and of maximal pedalling velocity by 4%, and a moderate inverse relationship between rP_{max} and age (r=-0.33) (Bonnefoy et al., 1998). A comparison between younger (31 years) and elder men (69 years) suggested a lower Pmax in the latter group by 27% (Marsh, Paterson, Govindasamy, & Cunningham, 1999). A research on oarsmen and kayakers (30-67 years) reported a decline of peak power by 6-7% per decade (Ładyga, Faff, Borkowski, & Burkhard-Jagodzińska, 2009). Grassi and colleagues observed peak power in elder (75 years) lower by 50% than young (20 years) (Grassi et al., 1991). In men 20-88 years, the decline in rPmax (10.3 % per decade) was higher than in aerobic capacity (7.5 % per decade) concluding that the age-associated decline

in anaerobic power was steeper than that of aerobic power (Kostka, Drygas, Jegier, & Zaniewicz, 2009). In highly trained master cyclists (35-64 years) rPmax declined at a rate of 8.1% per decade, whereas aerobic power did not change (Gent & Norton, 2013). Therefore, the findings of the present study confirmed for the first time in male marathon runners the decline of rPmax with aging observed by the abovementioned studies in other sport groups. Furthermore, our findings - lowest scores of the oldest group in rPmax and v_0, but not in F_0 - suggested that the decline in rPmax should be attributed to the decline of v_0 rather than to F_0.

Differences in anthropometric and force-velocity characteristics among performance groups

Race time correlated moderately with F_0 and Pmax; indeed, the higher the anaerobic power, the slower the race time, which was in line with the highest scores of anaerobic power observed in the slowest (Q4) performance group. These findings confirmed that fast marathon runners were not characterized by a high anaerobic power (Legaz-Arrese et al., 2011; Vuorimaa, 1996), and indicated that an increased anaerobic power might be related with slow race time. Based on these findings, the training of marathon runners should not emphasize on the development of Pmax.

Relationship between force-velocity and anthropometric characteristics

The anaerobic power correlated with both FFM and CSA, which might explain why the fast marathon runners are not characterized by high anaerobic power. An excess of FFM, even if this is 'active mass', is a load that marathon runners have to carry with them. Although an increased Pmax might improve the cost of running (Giovanelli et al., 2017), its association with increased FFM would lead to slower race time. The fastest group had the lowest BF, which was in agreement with research (Barandun et al., 2012; Knechtle et al., 2014) showing BF as predictor of race time in endurance running. Thus, it was concluded that the anthropometric characteristics of the marathon runners do not favour the development of high Pmax.

Strength of this study was its novelty since it was the first to examine the F-v characteristics of male marathon runners and the findings could be used as norms and references for future studies. Furthermore, the sample size (n=135) was one of the largest ever studied combining both laboratory and race data (e.g. n=84, male finishers in the Madrid marathon, Salinero et al., 2017; finishers in different marathon races, Tanda & Knechtle, 2015) and this allowed the meaningful comparison among age and performance groups. In view of the increased participation in marathon races during the last decades (Lepers & Cattagni, 2012), the findings were of great practical value for strength and conditioning coaches in the context of training and testing of their runners. Moreover, from a theoretical perspective the results might interest scientists focusing on aging such as exercise physiologists and gerontologists.

Limitations

A limitation of the present study was the ergometer and protocol that assessed anaerobic power. F-v test and WAnT did not provide similar estimates and their findings should not be used interchangeably (Jaafar, Rouis, Attiogbe, Vandewalle, & Driss, 2016). In addition, anaerobic power was assessed on cycle ergometer and this choice might be criticized as non-sport specific (non-ecological) for marathon runners. Another limitation in the statistical analysis might be the comparison among different sized age groups. However, it should be highlighted that an uneven distribution of participants (most of them were in the 40-45 years age group and their number decreased as the age deviated from this range of age) into age groups was "ecologically" valid, since its pattern represented the distribution of finishers in marathon races. For instance, most finishers in the 'New York City Marathon', the largest marathon in the world, were in the 40-44 years age group (Nikolaidis &

Knechtle, 2018). On the other hand, the use of F-v test allowed the analysis of anaerobic power into its two components, i.e. (braking) force and (pedalling) velocity.

Conclusions

In summary, male marathon runners were characterized by low levels of anaerobic power compared to non-endurance athletes. The observed age-related differences were smaller than those previously shown in non-athletes. The small magnitude of age-related differences in anaerobic power among most age groups indicated that humans without muscle strength/power training might maintain anaerobic power indices till their 60's. An excess of anaerobic power might be disadvantageous for marathon runners, likely due to its relationship with excess of fat-free mass. Considering the gap in the existing literature about the F-v characteristics of marathon runners, these findings added new information.

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Conflict of Interest Statement

The authors declare that the submitted work was not carried out in the presence of any personal, professional or financial relationships that could potentially be construed as a conflict of interest.

Author contribution

PN and BK contributed equally to this work. PN performed the experiments and drafted the paper. BK helped in drafting the paper and edited the final version.

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Legends of figures

Figure 1 Force-velocity relationship of all participants represented by pedalling velocity against braking force 3, 4, 5 and 6 kg.

Error bars represent standard deviations. Dashed lines show 95% confidence intervals of linear regression.

Figure 2 Differences in theoretical maximal velocity (v_0), force (F_0), maximal power in absolute (Pmax) and relative values (rPmax), and v_0/F_0 among age groups.

* Different from <30 age group at $p<0.05$.

Figure 3 Differences in theoretical maximal velocity (v_0), force (F_0), maximal power in absolute (Pmax) and relative values (rPmax), and v_0/F_0 among performance groups.

* Difference at $p<0.05$.

Q1, Q2, Q3 and Q4 represent performance groups based on quartiles of race time with Q1 the fastest and Q4 the slowest.

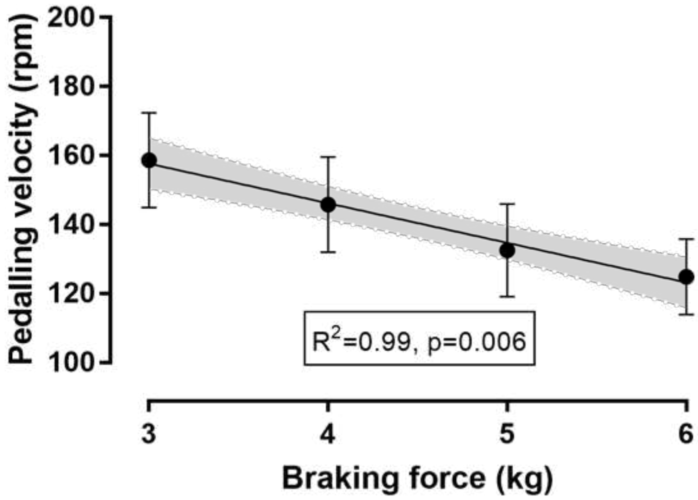

Pedalling velocity (rpm)
200
180
160
140
120
100
R^2=0.99, p=0.006
3
4
5
6
Braking force (kg)

Figure 1

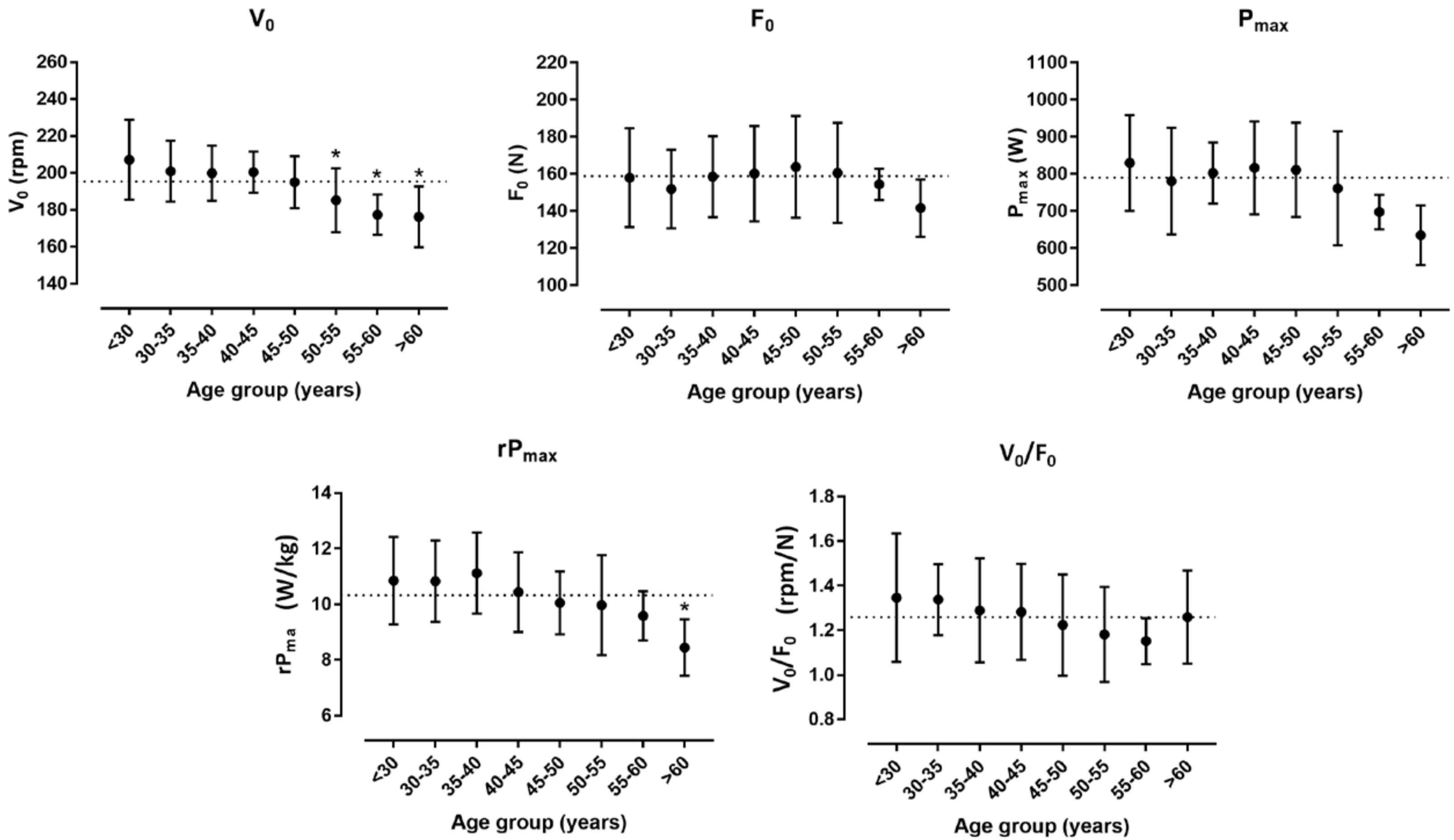
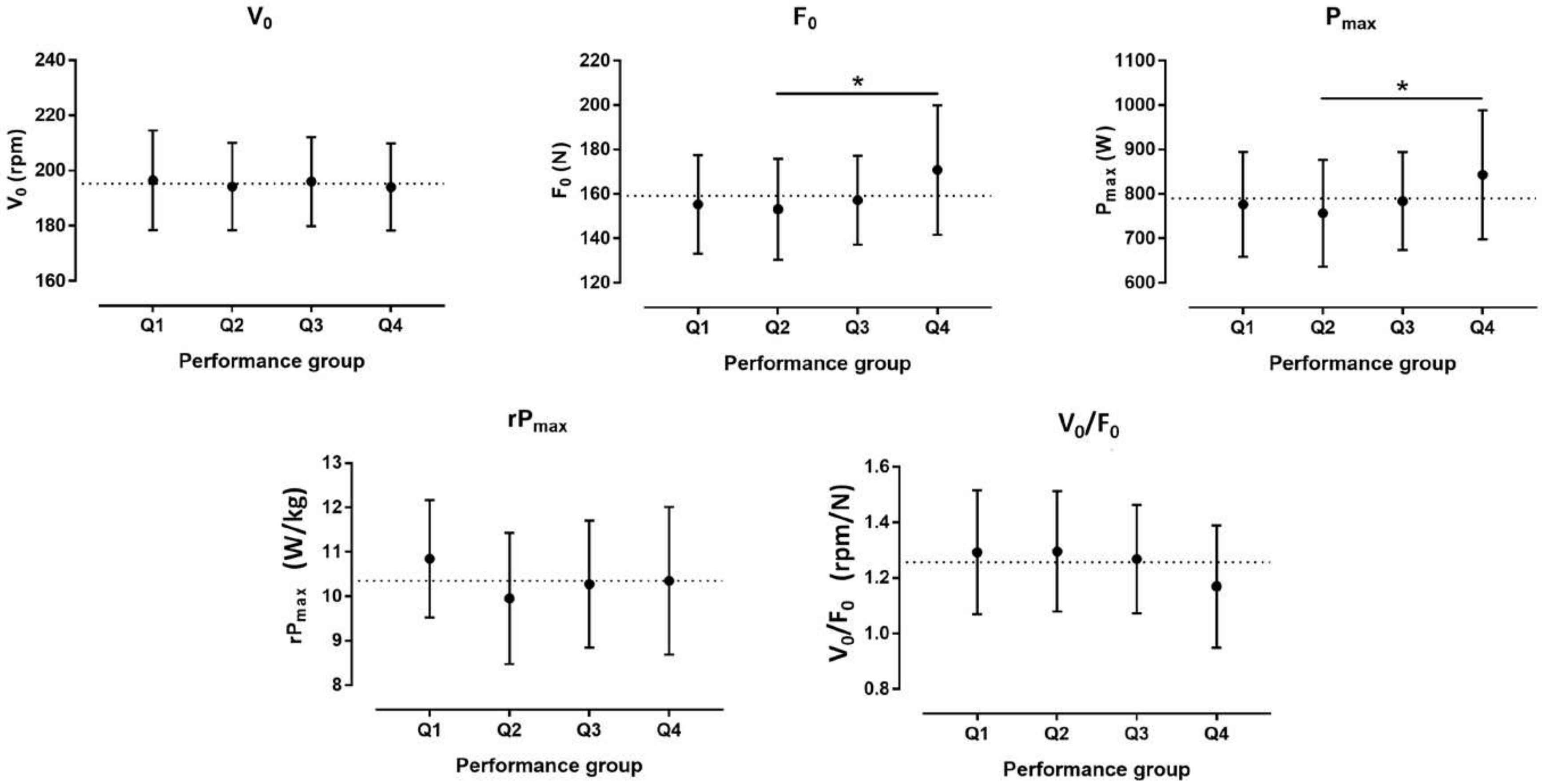

V0
V0 (rpm)
260
240
220
200
180
160
140
*
*
*
<30
30-35
35-40
40-45
45-50
50-55
55-60
>60
Age group (years)
F0
F0 (N)
220
200
180
160
140
120
100
<30
30-35
35-40
40-45
45-50
50-55
55-60
>60
Age group (years)
Pmax
Pmax (W)
1100
1000
900
800
700
600
500
<30
30-35
35-40
40-45
45-50
50-55
55-60
>60
Age group (years)
rPmax
rPma (W/kg)
14
12
10
8
6
*
<30
30-35
35-40
40-45
45-50
50-55
55-60
>60
Age group (years)
V0/F0
V0/F0 (rpm/N)
1.8
1.6
1.4
1.2
1.0
0.8
<30
30-35
35-40
40-45
45-50
50-55
55-60
>60
Age group (years)

Figure 2



V0
240
220
200
180
160
V0 (rpm)
Q1
Q2
Q3
Q4
Performance group
F0
220
200
180
160
140
120
F0 (N)
*
Q1
Q2
Q3
Q4
Performance group
Pmax
1100
1000
900
800
700
600
Pmax (W)
*
Q1
Q2
Q3
Q4
Performance group
rPmax
13
12
11
10
9
8
rPmax (W/kg)
Q1
Q2
Q3
Q4
Performance group
V0/F0
1.6
1.4
1.2
1.0
0.8
V0/F0 (rpm/N)
Q1
Q2
Q3
Q4
Performance group

Figure 3

Table 1. Comparison among age groups.

	Age groups							
	<30	**30-35**	**35-40**	**40-45**	**45-50**	**50-55**	**55-60**	**>60**
n	7	9	25	34	31	16	6	7
Age (years)	26.7±2.6	32.2±1.4	37.9±1.6	42.4±1.4	47.2±1.5	52.0±1.2	58.2±1.7	64.8±4.0
Height (cm)	177±5	176±5	176±6	178±6	177±5	176±6	174±9	172±6
Body mass (kg)	76.6±7.1	72.2±9.5	72.8±7.0	78.5±9.1	81.0±11.2	76.3±8.1	73.1±5.4	75.5±8.5
BMI (kg/m^2)	24.5±1.6	23.4±2.4	23.6±1.9	24.7±2.3	26.0±3.4	24.6±2.0	24.1±0.9	25.7±3.4
BF (%)	15.7±4.7	14.7±3.6	16.3±4.3	18.1±3.2	19.1±4.6	18.2±.2	16.8±4.5	19.0±4.2
FFM (kg)	64.4±4.2	61.4±6.4	60.7±4.1	64.2±6.5	65.2±6.9	62.3±6.3	60.7±4.5	60.9±4.2
CSA (cm^2)	147±5	144±17	138±15	146±13	143±14	141±13	132±12	132±11

BMI=body mass index, BF=body fat percentage, FFM=fat-free mass, CSA=thigh muscle cross-sectional area. *$p<0.01$, $^{\dagger}p<0.001$

Table 2. Comparison among performance groups (quartiles).

	Performance groups			
	Q1 (n=32)	**Q2 (n=33)**	**Q3 (n=35)**	**Q4 (n=33)**
Age (years)	40.9±9.5^{*Q4}	43.7±9.6	43.9±7.9	48.3±6.9^{*Q1}
Height (cm)	176±6	177±6	177±6	176±6
Body mass (kg)	71.7±8.2$^{\dagger Q4}$	76.4±8.9	76.6±7.2	81.9±10.2$^{\dagger Q1}$
BMI (kg/m^2)	23.0±1.9$^{\dagger Q4}$	24.5±2.6^{*Q4}	24.5±1.6^{*Q4}	26.5±2.9$^{\dagger Q1,*Q2,*Q3}$
BF (%)	14.1±3.9$^{\dagger Q2,\dagger Q3,\dagger Q4}$	17.9±3.6$^{\dagger Q1}$	18.0±2.9$^{\dagger Q1}$	20.1±3.5$^{\dagger Q1}$
FFM (kg)	61.3±5.7	62.6±6.3	62.7±5.4	65.2±6.4
CSA (cm^2)	136±14	142±12	143±13	145±16

Q1, Q2, Q3 and Q4=quartiles of race time, BMI=body mass index, BF=body fat percentage, FFM=fat-free mass, CSA=thigh muscle cross-sectional area. *$p<0.01$, $^{\dagger}p<0.001$